Probing the polarized gluon content of the proton through χ_2 hadroproduction[1]

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Abstract

Determining how much spin is carried by gluon in a polarized proton is a fundamental problem which cannot be resolved by completely inclusive deep inelastic measurements. Hadroproduction of heavy flavors is very sensitive to the gluon content of hadrons. We show that $\chi_2(3555)$ production in polarized proton-proton collisions is a good candidate reaction to address this challenging question.

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Charmonium spectrum and decays are quite well understood in the framework of perturbative QCD because these states are small nonrelativistic systems of heavy quarks. The production of charmonia in hadron-hadron collisions is expected to be dominated by gluon fusion mechanisms. Whereas J/ψ production seems to be subject to important higher twist contributions [1], namely those where two gluons from a single hadron interact with a gluon from the other hadron, the production [2] of χ_j states is phenomenologically [1] well under control in the simple leading twist picture where two gluons (one from each hadron) fuse to give at leading order a 1^+ $c\bar{c}$ state with zero transverse momentum. Among these states, $\chi_2(3555)$ is remarkably sensitive to incident gluon polarizations [3] and thus deserves careful investigation.

Neglecting $O(\alpha_S)$ corrections and internal transverse momenta in the proton, the production cross section (at zero transverse momentum) is given by[4]

$$\sigma(x_F \geq 0) = \frac{M^2}{s} \int \frac{dx_1}{x_1} \; G(x_1, M^2) \; G(\frac{M^2}{x_1 s}, M^2) \sigma_0(gg \to \chi_2) \tag{1}$$

where M is the χ_2 mass and

$$\sigma_0(gg \to \chi_2) = 16\pi^2 \alpha_s^2 \mid R'_P(0) \mid^2 /M^7, \tag{2}$$

reasonable estimates of the parameters being [1], $\alpha_S = 0.26$ and $\mid R'_P(0) \mid /M = 0.006 Gev^3$.

The helicity amplitudes for producing the χ_2 meson with $J_z = 0, \pm 1$ vanish (unless non leading internal transverse momentum effects are kept). Thus, χ_2 is only produced with $J_z = \pm 2$ and the sign of J_z is directly reminiscent of the helicities (μ and μ') of the incident gluons. Indeed the only non-vanishing amplitudes are those for

$$g(\mu = 1) + g(\mu' = -1) \to \chi_2(J_z = +2) \tag{3}$$

and

$$g(\mu = -1) + g(\mu' = 1) \to \chi_2(J_z = -2) \tag{4}$$

This makes χ_2 a beautiful probe of the gluon spin content of the proton.

When both beam and target are polarized, one measures cross sections $d\sigma_{ij}$ for incident hadron helicities i and j, and defines an asymmetry as

$$A(x_F) = \frac{\frac{d\sigma_{++}}{dx_F} - \frac{d\sigma_{+-}}{dx_F}}{\frac{d\sigma_{++}}{dx_F} + \frac{d\sigma_{+-}}{dx_F}} \tag{5}$$

which measures how much gluons remember the spin state of their parents through

$$A(x_F) = \frac{\Delta G(x_1, M^2)}{G(x_1, M^2)} \; \frac{\Delta G(x_2, M^2)}{G(x_2, M^2)} \tag{6}$$

with x_1 and x_2 detemined from measurable quantities through the usual relations: $x_F = x_1 - x_2$ and $M^2/s = x_1 x_2$.

When only the target is polarized, one needs to measure a transmitted asymmetry, *i.e.* to recognize a $J_z = +2$ χ_2 state from a $J_z = -2$ one. This requires analizing χ_2 decay channels. The most interesting channel is the electromagnetic decay

$$\chi_2 \to J/\psi + \gamma \tag{7}$$

the rate of which is around 13 per cent. In the heavy quark limit, this transition is of the electric dipole type, *i.e.* it preserves the quark spins. The angular decay distribution is thus known as

$$\frac{d\Gamma}{d\theta} = \frac{3}{16\pi}(1 + cos^2\theta) \tag{8}$$

and the polarization of the photon along the beam direction is simply given by [3]

$$\mathcal{P}_\gamma = -\frac{\cdot\mathcal{G}(\S_\in, \mathcal{M}^\in)}{\mathcal{G}(\S_\in, \mathcal{M}^\in)} \quad . \tag{9}$$

Measuring this outgoing photon polarization is an experimental challenge but the rewards are high; it is worth considering it in more details.

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References

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